NRAC

AVIATOR
PHYSICAL
STRESS

NAVAL RESEARCH ADVISORY COMMITTEE

PANEL ON

AVIATOR PHYSICAL STRESS

SUMMER STUDY

JULY 1990

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I. EXECUTIVE SUMMARY

The effect of physical stress on the tactical aviator and its impact on mission performance was examined. The physical stresses identified, all consequences of rapid-onset or sustained acceleration during flight, include G-induced Loss of Consciousness (G-LOC), Spatial Disorientation (SD), and neck injury.

Though SD as a predominate cause of controlled flight into the terrain has been known for many years, widespread reporting of G-LOC and cervical injury has only occurred during the past decade, coincident with the introduction of high performance, agile aircraft (F-15, 16, 18). The Naval Medical Research and Development Command (NMRDC) requested that the Naval Research Advisory Committee (NRAC) convene a panel to study these problems.

Emerging Tactical Aviation (TACAIR) technology will increase the adverse effects of Aviator Physical Stress (APS). The next generation of aircraft will be highly maneuverable and capable of sustaining high-G levels without severe energy tradeoffs. Additionally, the extra weight attributed to helmet-mounted video display systems, night vision aids and laser protective devices will increase the hazard of neck injury in flight.

The study begins with a discussion of the historical perspective, changing operational environment, and the impact of emerging technology on APS. A multi-faceted approach to reducing such stress requires modification of training, equipment, research, and organizational responsibility.

The Panel summarized its observations as follows:

1. High performance, agile tactical aircraft used in complex mission environments have exacerbated APS, including G-LOC, SD, and neck injury. These worsening problems require immediate attention if the Navy is to minimize costly consequences.

2. The Panel recommends that project area coordinators be identified for each type of physical stress. OP-05 and MED-02 should assure coordination between fleet requirements, equipment, and training on the one hand, and the medical research and development (R&D) labs on the other. We suggest that progress be reported to the Assistant Secretary of the Navy for Research, Development and Acquisition [ASN (RD&A)], at least annually.

3. The Naval Safety Center (NSC) has obtained insufficient data to effectively document the magnitude of the APS problem. This lack of data

has impeded focused R&D, training modifications and equipment validation.

4. While some research has been directed towards understanding APS, there remain a number of areas of research which require additional focused resources and priority support.

5. New and/or modified equipment can be employed to inhibit G-LOC, cervical injury, and SD. These include positive pressure breathing (PPB) and extended coverage G-suits; advanced cockpit orientation awareness and automated ground-proximity systems; and lighter protective helmet systems.

6. Significant reduction of the consequences of APS will improve the effectiveness and safety of naval aviation.

II. TERMS OF REFERENCE

General Objective: Provide an assessment of the effect of physical stress generated during aviation combat maneuvers and the consequences of such stresses on short and long term mission performance. The assessment should address present and future high performance aircraft and unique platforms that create novel types of physical stress.

Background:

a. During the past year, it has been learned that up to one-third of the F-16 squadrons in Europe are operating at reduced capacity. This is allegedly due to neck injuries sustained by aviators during high G-force maneuvers. While such injuries appear transient, they have a clear impact on mission performance. It is likely that such injuries have also been seen in pilots of any high performance aircraft capable of rapid G-onset and high G-forces (>6).

b. The availability of unique sensors and technologies has led to the attachment of several devices to the aviator helmet. Targeting and night vision devices are presently mounted, and laser dazzle protective gear are under development. The addition of such systems adds weight to the helmet and changes the center of gravity such that they may exacerbate forces during high G-maneuvers, especially during visual reconnaissance of the aft quadrants.

c. Other physical stresses include the transient loss of consciousness due to G-forces. This syndrome known as G-LOC is reduced by the use of pressure suits and employing straining maneuvers, both of which prevent blood from pooling in the body's lower extremities. More recently, forced breathing systems (Demand PPB) have been employed, but the long-term effects of such forms of therapy are unclear.

d. The introduction of aircraft capable of swift vertical and lateral movements will likely exacerbate the types of pilot SD and disability currently observed during certain maneuvers.

Specific Tasking:

a. Analyze the current information on G-induced injuries and loss of consciousness and formulate recommendations for detecting and minimizing such problems. Include an analysis of helmet weight as a factor in potential neck injuries and the potential for worsening of such problems as highly agile aircraft are deployed.

b. Evaluate the current knowledge of aviator disorientation and provide recommendations for methods to reduce such effects.

c. Provide recommendations concerning additional research needed to address the above mentioned problems.

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IV. BRIEFING CHARTS AND TEXT

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AVIATOR PHYSICAL STRESS

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  - BRIEFINGS
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  - CHANGING THREAT & OPERATIONAL ENVIRONMENT
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  - RESEARCH
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    - TECH BASE
    - ADVANCED
  - ORGANIZATIONAL STRUCTURE
- SUMMARY & RECOMMENDATIONS

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PURPOSE

AVIATOR PHYSICAL STRESS

- **Examine the Effect of Physical Stress on Tactical Aviation and Its Impact Upon Mission Performance.**
- **Provide Recommendations to Reduce Such Effects.**

BRIEFINGS/DISCUSSIONS

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VF-126

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BACKGROUND

- Historical Perspective
- Changing Threat and the Operational Environment
- Impact of Emerging Technology

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BACKGROUND

AVIATOR PHYSICAL STRESS

HISTORICAL PERSPECTIVE

1919 **First Known Episode of G-LOC**

1981 **USMC A-6 (fatal): Suspect G-LOC**

1984 **USAF: G-LOC Major Concern**

1987 **USN: Spatial Disorientation Fleet Concern (TOR generated)**

1988 **USN/USAF Report Neck Pain/Injury Degrade Performance (anonymous surveys)**

1989 **USAF G-LOC Mishaps Increase**

1990 **NMRDC Urges NRAC Study**

The first documentable episode of G-LOC occurred during an air race in 1919. Because of the inherent difficulty in determining G-LOC as the causal factor in fatal mishaps, it has only been during the past decade that accident investigation boards have been able to increasingly pinpoint this as the cause of some aircraft accidents. Five such accidents in 1984 prompted the Air Force to embark on training and equipment modifications designed to better protect the pilot from this phenomenon.

Though the serious consequences of SD have long been known in the aviation community, the conceptual framework has broadened because of increased night and low level operations. In 1987, fleet pilots (F/A-18) generated a Tentative Operational Requirement (TOR) for a SD/situational awareness trainer, indicating concern about this problem on the part of the aviator.

With the introduction of more agile, high performance aircraft, neck pain and injury resulting from the effects of G-loads have been reported mostly through surveys of tactical aircrews in the Navy and Air Force, and to some extent through safety and aeromedical channels.

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BACKGROUND

AVIATOR PHYSICAL STRESS

CHANGING THREAT AND OPERATIONAL ENVIRONMENT

The geopolitical environment and related threat scenarios appear to be changing; however, the technological threat and operational environment continue to intensify.

The adverse affects of APS have been observed and recorded over an extended period of time. Throughout this period, whether during global conflict, police actions or peace-time, the incidence of APS and resulting problems has consistently trended towards increasing severity.

BACKGROUND

AVIATOR PHYSICAL STRESS

IMPACT OF EMERGING TECHNOLOGY

Highly Maneuverable Aircraft
- **Aerodynamics**
- **Tactics ("point and shoot")**

Next Generation Fighters Increased G-Induced Stress

Mission Enhancement Devices
- **Night Vision**
- **Laser Protection**
- **Helmet Mounted Display**

Increased Helmet Weight and Altered Center of Gravity

Research/Training
- **Advanced Spatial Disorientation Trainer (ASDT):**
  - **USAF funded as training device vs research equipment**

Emerging TACAIR technology will increase the adverse effects of APS. The next generation aircraft will be highly maneuverable and capable of sustaining high G-levels without severe energy tradeoffs. Thus, the tactical utility of offensive and defensive sustained maneuvering will increase. High G-onset rates to support "Point and Shoot" tactics will further aggravate the situation.

Additionally, off-boresight cueing/targeting and helmet-mounted video display systems and laser protective devices will increase the hazard of neck injury in flight. At the same time, night operations with multiple sensors and low level operations will make the present problem of SD even worse.

PHYSICAL STRESS IMPAIRING PERFORMANCE

TOPICS

- G-LOC
- Spatial Disorientation
- Neck Injury

FORMAT

- Definition
- Causal Factors
- Supporting Data

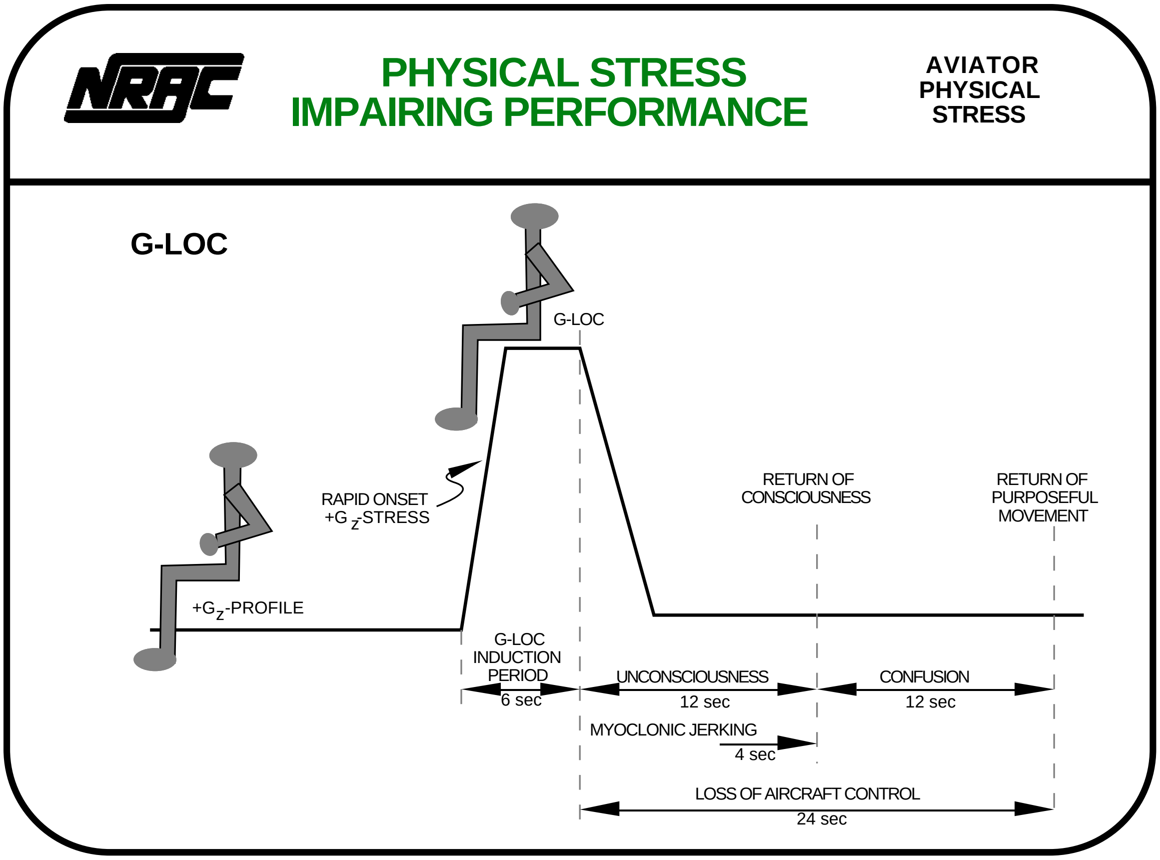
PHYSICAL STRESS IMPAIRING PERFORMANCE

AVIATOR PHYSICAL STRESS

G-LOC DEFINTION

The Abrupt Loss of Consciousness Induced by the Reduction of Blood Flow to the Brain Resulting from Exposure to $+G_z$ Stress

Acceleration ($+G_Z$, head-to-foot) G-LOC has been documented to have occurred in aviation since 1919. At the onset of G-LOC, the pilot's brain becomes dysfunctional, and nonrecognition of the event makes recovery difficult. This difficulty in recognizing G-LOC, along with the medical standards that disqualified aviators who experienced G-LOC, resulted in keeping in-flight G-LOC "in the closet" for many years. As a result, almost no research was conducted while the development of highly maneuverable fighter/attack aircraft increased the G-LOC threat. G-LOC as a causal mishap factor frequently requires extremely careful analysis based on detailed investigation by highly trained specialists. Recent research has confirmed that G-LOC results from reduced blood flow to the brain. Much remains to be discovered concerning the exact neurophysiologic mechanism of G-LOC.



The neurophysiologic characteristics of G-LOC are critical to understanding the adverse effects of rapid-onset, high-sustained +G_Z on the tactical aviator. A normal aviator can generally tolerate such +G_Z-stress for up to 6 seconds without any symptoms because of the brain's resistance to an abrupt reduction in blood flow. Reduced blood flow for longer periods results in an average unconscious period of 12 seconds followed by an average confusion and disorientation period lasting another 12 seconds. Should G-LOC occur, the total time an aviator would not be in control of his aircraft would be approximately 24 seconds. This is indeed a long period of uncontrolled flight in a tactical aircraft. Uncontrolled muscular jerking frequently occurs as consciousness is regained and has resulted in the inadvertent activation of cockpit systems, for example, landing gear deployment at high airspeeds. These G-LOC kinetic relationships are keys to understanding the normal responses of the body to reduced blood flow to the brain, and important for aircraft mishap investigations. They also form the foundation upon which efforts are based to prevent in-flight G-LOC and reduce incapacitation.

PHYSICAL STRESS IMPAIRING PERFORMANCE

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G-LOC SUPPORTING DATA

- **TACAIR Reporting (anonymous):**
  - **USAF 12%**
  - **USN 14%**
  - **RAF 19%**

  } **G-LOC ≥ 1 episode**
- **Centrifuge Data:**
  - **50% of aircrews do not recognize G-LOC**
- **Probable In-Flight Occurrence: 24-38%**
- **Class A Mishaps USAF/USN: 22 (1980-89)**
  - **(high probability of under reporting)**

Quantification and documentation of G-LOC impact on tactical operations is difficult. The reasons for the difficulty are two fold. First, aviators are often times aware of G-LOC episodes due to the nature of the phenomenon; and, secondly, aviators do not report G-LOC due to potential disqualification from flight duties. To address the difficulty an anonymous survey was administered to aviators in the mid-1980's and more recently centrifuge data collected during G-tolerance training exercises. Survey data indicated the twelve to nineteen percent of the aviators reported having experienced at least one recognized in-flight episode of G-LOC. Centrifuge data has shown that at least 50% of aircrews do not recognize G-LOC when it occurs. Therefore, it is probable that in-flight G-LOC has been experienced by 24 to 38 percent of tactical aviators. Between 1980-89, at least 22 G-LOC Class A mishaps have occurred in United States TACAIR. It is very likely that under reporting of G-LOC as a causal factor in naval aviation mishaps exists. The G-LOC threat is present in every tactical aircraft and increases as advanced aircraft enter the operational inventory. G-LOC continues to be most frequently reported in student aviator training (2-3 episodes/month) and extends throughout TACAIR including developmental aircraft (Northrop F-20). Surprisingly, most reported G-LOC incidences in the Navy occur in T-34 aircraft at a mean of 3.5 G.

PHYSICAL STRESS IMPAIRING PERFORMANCE

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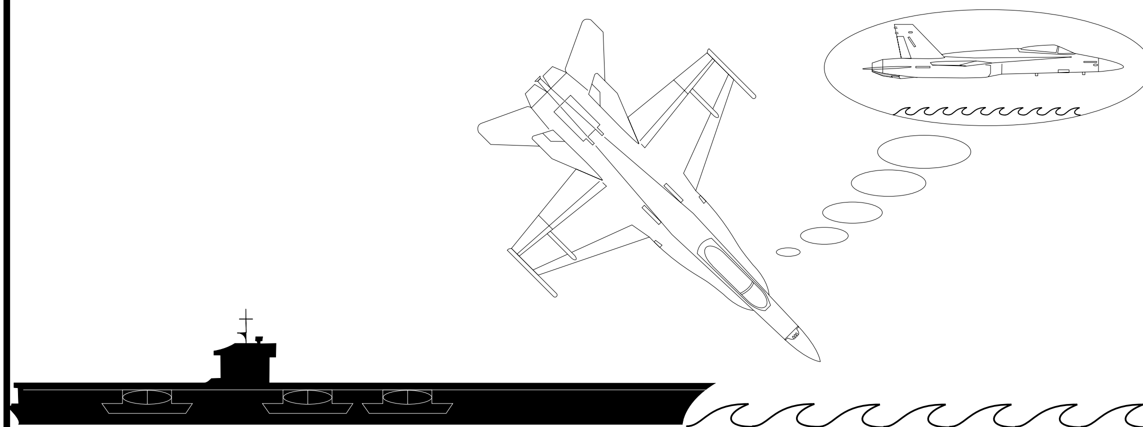
SPATIAL DISORIENTATION DEFINITION



Incorrect perception of attitude, altitude, or motion of own aircraft relative to the earth or other significant objects

All pilots experience SD at one time or another in flight. For this reason, the pilot must be equipped and trained to maintain control of flight despite disorientation. New equipment such as night vision devices lead to ventures into flight environments never before dreamed possible, like nap-of-the-earth or low-level flying at night, where the risk of SD mishap is high. In an effort to aid the pilot in his ability to achieve and maintain “situational” or “big picture” awareness, new sophistication of technology has made the pilot a manager of multiple systems. This increase in workload also increases the risk of SD episodes. Bottom line - pilots continue to fly into the ground.

PHYSICAL STRESS
IMPAIRING PERFORMANCE

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**SPATIAL DISORIENTATION
CAUSAL FACTORS**

In the absence of visual reference (real or instrument horizon), the direction of the resultant force vector is the only sensory indicator of which way is up ... and it is most often wrong!

Factors contributing to orientation - disorientation:

- **Aircraft Design**
- **Display Design - Integration**
- **Mission Demands - Task Load**
- **Training**
- **Sensory Information**

SD is a very complex problem. All of the body systems involved in the voluntary control of eye, head and body motion relative to the earth are intimately related. These include the visual and vestibular systems, somatoreceptors (muscle, joint and skin receptors), memory of preceding motion, expectation based on planned action and sensorimotor interactions. In flight, all of these systems function while the direction and magnitude of the normal gravitational cue to attitude control is constantly being changed by every little acceleration of the aircraft. The business of flying requires control of motion in three dimensional space. For the above reasons, disorientation in flight is a normal reaction and pilots must achieve orientation awareness quickly by artificial information from cockpit displays. When workload intervenes, the pilot is at high risk for a SD mishap. What are the factors that contribute to pilot orientation or disorientation? Aircraft design will have much to do with pilot susceptibility to SD. Display design and integration is key in allowing the pilot to achieve and maintain orientation and to rapidly re-orient himself should he become disoriented. Training is a powerful tool in the SD arena. Pilot awareness of SD hazard potential and the manifestations of SD is a must. Skill level and proficiency in instrument flying, task management, and coping with SD are directly related to SD risk potential.

The complexity of SD and its causes produces skepticism about the ability to fix it. SD cannot be eliminated, but pilots can be given training and improved instruments to maintain good spatial orientation awareness. Some disorienting conditions can be operationally avoided. Safety nets can be developed to avert fatal outcomes. A coordinated cooperative effort between training, research, fleet users, and systems acquisition is required. Such coordinated effort will be economically beneficial relative to costs of continued SD losses.

PHYSICAL STRESS IMPAIRING PERFORMANCE

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SPATIAL DISORIENTATION SUPPORTING DATA

USN	10 fatalities / year	Hundreds of $Millions / year
USAF	7 - 10 fatalities / year	
USN	'69 - '73 ~ 6 fatalities / year ~ 7 helo mishaps / year	
USA	'80 - '87 ~ 5 fatalities / year ~ 7 major helo mishaps / year	
RNLAF	17 F-16s lost in 10 year period; SD a factor in 7	
RAF	15% of helicopter accidents; 33% of helicopter deaths	
CAF	13 CF-18s lost to date; 6 suspected to be SD	
FAA	Cause or factor in 16% of fatal general aviation accidents	

Spatial disorientation is global, cutting across branches of the military services, nations, and civilian aviation. In addition to the costs of aircraft and aircrew losses, substantial costs are associated with mission failures and reduced effectiveness. SD mishap incidences may increase because of increased pilot workload, all-weather flight capability, and reduced proficiency due to reduced flight hours.

SD is classified into three types. Type I refers to the pilot who is disoriented but unaware of his disorientation. This type is the most common cause of SD mishaps in fixed-wing aircraft. Strong accelerative forces are not necessarily involved. Undetected acceleration can cause Type I SD. The pilot confidently maintains control of the aircraft until impact. In Type II SD, the pilot is disoriented but becomes aware of it. When his margin of error relative to the earth or other aircraft is sufficient, he corrects without mishap. Type III, incapacitating SD, is less common. Pilots have reported being incapacitated due to reflexive eye or limb control, violent tumbling sensations, or severe and persistent “leans." The pilot is aware of Type III SD but has difficulty, or may be completely unable to maintain control of flight. This type is more often associated with extreme flight maneuvers but can occur without exceptional accelerative conditions. Army statistics indicate that Types II and III SD account for the majority of helicopter SD mishaps.

PHYSICAL STRESS
IMPAIRING PERFORMANCE

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NECK INJURY
PROBLEM DEFINITION

Aviators in today's high performance tactical aircraft face a significant risk of neck pain and injury which can interfere with mission effectiveness.

An emerging body of clinical evidence suggests that physical stress on vertebrae and soft tissue in the necks of aviators has become a serious impediment to crew readiness and mission effectiveness. Symptoms ranging from neck muscle fatigue and soft tissue neck injury to vertebral injury and long-term degenerative disease have been observed and are believed to result from high G-onset and sustained accelerations, ejection procedures, and hard landings. The problem is more notable among pilots of F-16s and F/A-18s than prior aircraft and is exacerbated by increased helmet weight. All indications suggest that the problem will not improve in the future and may, in fact, get worse with the next generation of aircraft and helmet systems.

PHYSICAL STRESS IMPAIRING PERFORMANCE

AVIATOR PHYSICAL STRESS

NECK INJURY CAUSAL FACTORS

The risk of injury is related to:

- **High-G maneuvering capability of the aircraft**
- **Helmet characteristics**
- **Positioning of head and body**
- **Tactical environment**
- **Neck strength**

High G-maneuvers resulting in rapid G-onset and high sustained G-loads place enormous demands on the muscles of the neck to support the weight of the head and helmet. Helmet characteristics such as weight, center of gravity, and moments of inertia all influence the nature of the physical stress. Also, the position of the head and body relative to the motion of the aircraft contributes to the problem.

Different tactical environments place different demands on the aviators. For example, ground attack requires relatively less head movement than does air-to-air combat which demands considerable side-to-side motion and head rotation. Restriction of head movement due to neck pain can dramatically impede aviator effectiveness.

PHYSICAL STRESS
IMPAIRING PERFORMANCE

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**NECK INJURY
SUPPORTING DATA**

- **Up to 74% of surveyed aircrews report neck injuries (varies with type of aircraft)**
- **Decreased mission effectiveness has been reported in up to 56% of aircrews**
- **Serious injury (official temporary removal from flight status) up to 10% of aircrews**
- **Unofficial (self-selected) temporary removal from flight status of up to 30% of aircrews**

Survey data obtained from aircrews in the U.S. Navy (USN), U.S. Air Force (USAF), and several other North Atlantic Treaty Organization (NATO) air forces indicate high incidences of reported neck pain and injury. These data are consistent and show that the problem is greater in more agile aircraft. Mission effectiveness is compromised when pilots in pain restrict the range of their head and neck movements and remove themselves temporarily from flight status. Since most pilots consider a certain amount of neck pain to be an acceptable occupational hazard, significant underreporting of neck pain and injury is suspected. Though precisely accurate and validated epidemiological data is lacking, the consistency and pattern of the available data clearly support the operational significance of this medical problem. In extreme cases, severe neck injuries, including fractures and herniated disks, have occurred in tactical maneuvering flight. Though few in number, these are highly significant since they have occurred at acceleration levels much lower than are conventionally assumed to be required to provoke injury.

PHYSICAL STRESS IMPAIRING PERFORMANCE

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AERIAL COMBAT STRESS VIDEOTAPE

- **German Test Pilot**
  - **Inability to recognize G-LOC in centrifuge**
- **F-16B G-LOC near mishap**
  - **Instructor pilot recovery**
- **F-16A Fatal mishap**

(A five minute videotape of three separate Aerial Combat Incidents was shown to give a graphic video presentation of G-LOC.)

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SOLUTIONS

AVIATOR PHYSICAL STRESS

- **A Multi-faceted Approach to Reducing Aviator Physical Stress Consisting of the Following Elements is Proposed.**
  - **Training**
  - **Equipment**
  - **Research**
  - **Organizational Structure**
- **Ultimate Success Predicated Upon Retrieval of Operational Aviator Physical Stress Data.**

Solutions aimed at reducing the complex problem of APS should be multi-faceted involving training, equipment, research, and organizational accountability. Comprehensive APS data are necessary to define the magnitude of these problems, guide R&D, stimulate operational modifications of training, material, tactics, and organizational effectiveness, as well as monitor the effect of these modifications. It was apparent to the NRAC Panel that current Navy data on G-LOC, SD, and neck pain/injury are inadequate, and this lack of data has adversely impacted training, equipment, and research. In order to obtain accurate and comprehensive operational APS data, it is recommended that the responsibility for defining and obtaining relevant and usable data be carefully assigned. An effective mechanism for the implementation of data collection, storage, and retrieval should be established and monitored. The performance of in-flight pilot video monitoring, perhaps on a limited basis, would be an ideal mechanism to obtain direct operational data on the occurrence of G-LOC, head and neck kinematics, and contributing factors to SD. In-flight monitoring should also incorporate applicable physiological monitoring. Data obtained should be reviewed in a strictly non-attributional manner until their significance is clarified.

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SOLUTIONS

TRAINING

WHAT
- **Initial G-awareness instruction**
- **G-tolerance improvement training**
- **Spatial disorientation awareness**
- **Potential for G-related neck injury**

WHO
- **Instructors**
- **Flight Surgeons**
- **Aviation Psychologists & Physiologists**
- **Aircrews**

Current training in SD, acceleration physiology and tolerance must be revitalized and enhanced to allow aviators to better understand and respond to these phenomena. Required training, some of which is in place, includes: initial G-awareness instruction, SD awareness to include classroom and device instruction, G-tolerance improvement training (centrifuge), and G-related injury potential training.

Aviation physiologists, psychologists and flight surgeons require training to allow them to understand the mechanisms and potential operational impact of these problems. In addition, those individuals who will be responsible for administering the training should complete an instructor training course.

Aircrews require different types of training at different phases of their flying career.

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TRAINING

WHEN

- **Flight Surgeon/Physiologist/Psychologist initial training and yearly updates to maintain currency**
- **Aircrew:**
  - **Initial G-awareness and SD-primary flight training**
  - **G-tolerance improvement training (including centrifuge)**
    - **Prior to Fleet Replacement Squadron (FRS) assignment**
  - **G-related injury potential - FRS syllabus**
  - **Ongoing training - Safety Center via squadron Safety Officer/ Aeromedical Safety Officer/Flight Surgeon**

CURRICULUM DEVELOPMENT

- **Must be coordinated effort**

Aviation physiologists, psychologists and flight surgeons should receive initial orientation training as well as annual refresher training to allow for updates on new developments in these areas.

Primary flight training for aviators should include classroom sessions on SD and the physiological effects of G-LOC, as well as discussions of techniques for minimizing the adverse effects of these phenomena. The straining in the Multi-Station Spatial Disorientation Demonstrator (MSDD) would be the second component of SD training. Since the T-34 phase of flight training has the highest reported incidence of G-LOC, a G-awareness maneuver should be included as part of the primary flight syllabus. Such a maneuver should occur prior to requiring the student naval aviator to perform aerobatic maneuvers and could be included in the first aerobatics flight.

G-tolerance improvement training, to include centrifuge training, should occur following designation as a naval aviator and prior to reporting to a TACAIR Fleet Replacement Squadron (FRS).

G-related head and neck injury potential and techniques to reduce the likelihood of occurrence should be included as a part of the FRS syllabus, prior to the air combat maneuvering or equivalent phase of training.

Ongoing training in the areas of G-LOC, G-tolerance, SD, and neck injuries should be conducted at the squadron level using data disseminated by the Naval Safety Center (NSC).

To ensure proper focus, scope, and effectiveness of training, those tasked with curriculum development must integrate fleet and subject matter expert inputs. Specific examples of where this type of coordination is needed now are during the G-Tolerance Improvement Program (G-TIP) and during SD training. Since G-TIP was developed to increase pilots' G-tolerance, and is the Navy's choice for centrifuge training, it is imperative that the curriculum developers be directed to seek input from fleet aviators who have participated in preliminary centrifuge training at the Naval Air Development Center (NADC). The expertise of the current conductors of centrifuge training must also be tapped to ensure maximum effectiveness of training. In the SD area, a simple way to enhance the effectiveness of MSDD use would be to establish an official line of communication between the researchers at the Naval Aerospace Medical Research Laboratory (NAMRL) and the instructors at the Naval Aerospace Medical Institute (NAMI).

SOLUTIONS

AVIATOR PHYSICAL STRESS

EQUIPMENT

G-LOC
- **Incorporate Positive Pressure Breathing (PPB) and extended coverage G-suits**
- **Incorporate advanced integrated life support technology (long-term)**

SPATIAL DISORIENTATION
- **Develop display technologies to improve spatial orientation and decrease aircrew workload**

NECK INJURY
- **Develop helmet systems not to exceed 3.5 pounds**

PLATFORM ENHANCEMENT
- **Automatic ground-proximity recovery system**
- **Accident recoverable in-flight data recording**

Near term and long term equipment solutions are available to address the problem of APS.

G-LOC

Information obtained in the course of presentations to the NRAC panel indicates that anti G-suit fit has not been optimized for everyday operational use. This has probably led to a reduction in G-force protection for tactical aircrews. It is important that advanced anti G-suits are designed to ensure optimal fit and ease of use by the aircrews.

Technologies are already available which can enhance $+G_Z$ protection significantly over current equipment configurations. Prominent among these are assisted PPB systems, extended coverage G-suits, and improved G-valves and breathing regulators. It should be emphasized that fleet aviators believe that the reduction of fatigue, provided by assisted PPB systems, is as important as protection against G-LOC. The assisted PPB systems will provide enhanced operational effectiveness in a sustained G-environment. Application of these technologies should be accelerated.

Longer term solutions may require the integration of G-protective devices

with advanced life support systems which also afford protection against Nuclear, Biological and Chemical (NBC), thermal, and other threats. Previous non-integrated, piecemeal approaches to aircrew protection have compromised overall system effectiveness and exacerbated other stressors. Careful integration — with a modular capability — will be the key to a successful future approach. Ideally, a future integrated protective ensemble will be "tailorable" to the minimum number of systems or modules that are needed for a particular mission.

SPATIAL DISORIENTATION

Attempts to reduce the problem of SD should focus on the enhancement of aircraft instrument displays so that spatial orientation information can be assimilated by the pilot more efficiently. Innovative display technologies and decision support systems which improve spatial orientation and decrease aircrew workload are needed. Auditory and tactile means of displaying orientation information should also be considered.

NECK INJURY

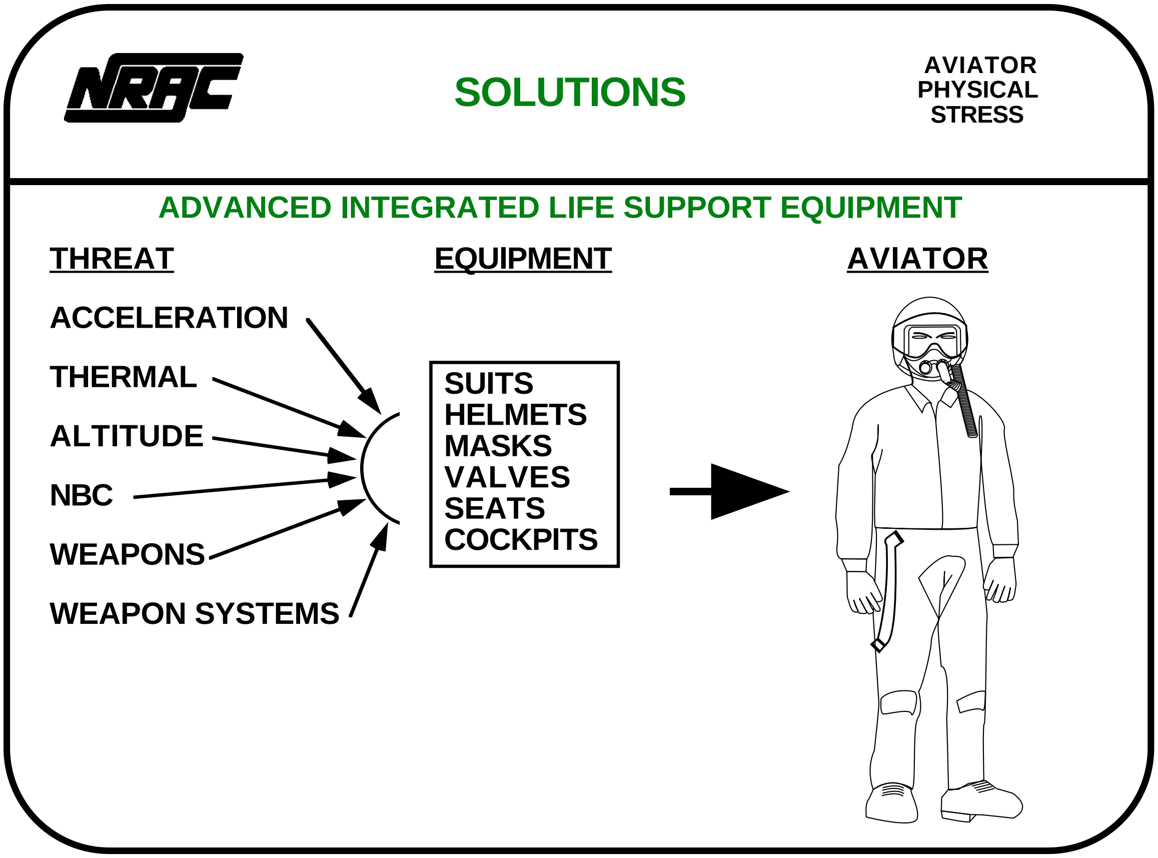
It is recognized that numerous compromises are required in order to simultaneously satisfy the requirements of mission effectiveness and pilot safety and comfort. Pilots, already overburdened, can expect additional demands with the advent of night vision devices, helmet mounted sighting and display systems, and anti-laser eye protection. An immense technical challenge exists to integrate these technologies into the helmet without placing the pilot at increased risk of neck injury in high G-maneuvers.

Neck injuries persist even with the lightest helmets now fielded. Definitive data which will enable the specification of the optimal helmet weight and configuration are not available. Nevertheless, it is recommended that 3.5 pounds (including mask) represents a reasonable upper limit for safe helmet system weight as long as the pilot's neck is the sole means of support for the helmet system. Additional systems should be added only with careful consideration to pilot safety within well characterized flight envelopes and emergency egress procedures. Maximum attention should be paid to developing and fielding the lightest helmet possible which optimizes the trade-offs between head protection, physiologic effects under acceleration and overall mission performance.

PLATFORM ENHANCEMENT

The above recommendations by themselves cannot be expected to eliminate the loss of aircraft and aircrews due to G-LOC and SD. It is, therefore, recommended that development and installation of automatic ground-proximity recovery systems for all tactical aircraft be considered.

In order to improve the understanding of the conditions and operating envelopes in which G-LOC, neck injury, and SD occur, information must be obtained from the operational environment. Therefore, it is also recommended that accident recoverable in-flight data recorders be developed and installed in all tactical aircraft. This information, in turn, should serve as the basis for the further reduction of the loss of aircraft and aviation personnel.



Increasing operational complexity in diverse environmental conditions results in multiple and often concurrent stresses to which the tactical aviator is routinely exposed. Theater operational realities introduce numerous stress phenomena. In addition to G-force, altitude and thermal extremes, protection against NBC and laser threats may also be required. Accordingly, protective devices have been integrated into the aviator's flight gear, resulting in complex and cumbersome life and mission support systems. Complicating this further has been the recent introduction of various helmet or aviator mounted devices such as night vision goggles or helmet mounted displays.

Careful integration of life support and mission essential equipment must be balanced against a myriad of tradeoffs to ensure optimal protection without degradation of aviator performance or mission effectiveness.

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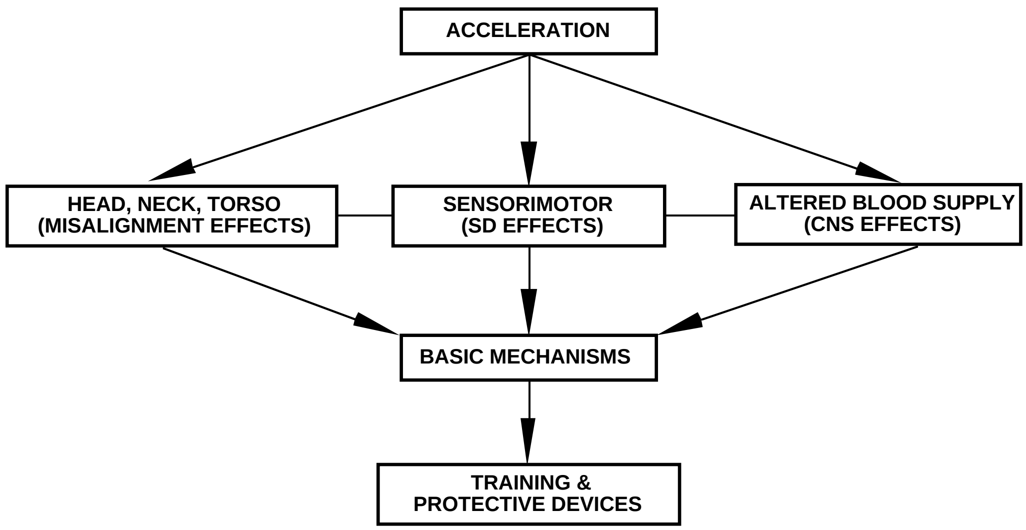
AVIATOR PHYSICAL STRESS

RESEARCH OVERVIEW



A priority research program is necessary to focus the Navy's understanding, and determine the corrective actions required to minimize the effects of APS. The panel's solutions identify coordinated and focused research approaches that require relatively small amounts of incremental funding.

The research is driven by the fact that the stressful acceleration experienced by naval aviators produces a variety of effects adversely affecting performance and mission effectiveness. These adverse effects include misalignment of head, neck and torso producing neck injury; sensorimotor responses producing SD; and altered cerebral blood supply producing central nervous system dysfunction. Though the details of the research requirements vary for each of these areas, existing Navy facilities and capabilities are adequate to implement a common overall approach to addressing solutions. The technology base must be enhanced by refining our understanding of the underlying physical and physiological mechanisms. This should be a focused approach designed to contribute directly to improved aviator training and protective equipment.

To achieve the research objectives efficiently, the capabilities of each of the Navy facilities must be coordinated in a focused fashion on the three problem areas. In addition, all Navy and Department of Defense (DOD) facilities involved in relevant work should be included in a functional network.

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AVIATOR PHYSICAL STRESS

RESEARCH - TECH BASE

Mechanisms and limitations of:

- **G-TOLERANCE**
  - **Neurophysiologic function during combat $+G_z$**
- **SPATIAL ORIENTATION**
  - **Human motion perception / control**
- **CERVICAL INTEGRITY**
  - **Biodynamic response to rapid onset and sustained acceleration**

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RESEARCH - ADVANCED

G-LOC

- **Improved high-G training technology**
- **Advanced protective equipment**

SPATIAL DISORIENTATION

- **Orientation enhancing instruments**
- **Improved training scenarios / systems**

NECK INJURY

- **Helmet system characteristics**
- **Neck position / strength relationships**

SOLUTIONS AVIATOR PHYSICAL STRESS

ORGANIZATIONAL STRUCTURE

- **Clarify OPNAV and BUMED roles for coordination and sponsorship of APS research, data collection and training**
- **Examples:**
  - **Develop and implement an organizational information network to facilitate technical data exchange**
  - **Use Operator Advisory Group for coordination of operational input into APS program network**
  - **Re-orient G-Tolerance Improvement Program (G-TIP) for maximum training effectiveness**

Many facilities have the capacity to provide improvements and solutions to the problems of APS. Relevant work is underway in medical and non-medical R&D facilities in the Navy, various USAF and U.S. Army (USA) laboratories and acquisition facilities, and international (especially NATO) institutions. This wide assortment of potential assets is at once a great opportunity for synergistic work, but all too often is the source of costly duplication of effort and missed opportunities for cooperative projects.

To effectively share and multiply information and research assets, an active management oversight and informational exchange group should be established for each element of APS. Specific individuals (Project Area Coordinators) located within critical agencies could be identified to participate. With an appropriate charter they could then "keep up" with current and planned work, and seize opportunities for efficient cooperation. Information from currently chartered working groups (such as DoD Technical Advisory Groups, NATO Standardization Working Groups, etc.) could then be introduced into this structured information system.

Additionally, information from the staff of the Chief of Naval Operations (OPNAV)-sponsored Operator Advisory Group (OAG) of fleet aircrews could be of immense benefit to those working in the field of APS. The NSC should

also be an important part of this information network. Specific areas of NSC information retrieval and solicitation should be enhanced, particularly in the areas of G-LOC and flight-related neck problems, and the information used to improve the direction of ongoing projects.

Staff of the Chief of Naval Operations (OPNAV) and the Bureau of Medicine and Surgery (BUMED) are the requirement and resource sponsors of R&D in APS technologies. BUMED currently directs medical laboratory assets and funds development programs that are responsive to naval air warfare technical problems. Since the deliverables of these programs are specifications and/or guidelines used by air warfare to improve the use and design of training systems, life support equipment, and aircraft systems/subsystems, funding participation by the air warfare sponsor is considered necessary.

G-TIP, currently managed by the Naval Air Systems Command (NAVAIR) PMA-205, was identified as a candidate program for the application of BUMED tech base developments. Navy technical and data base resources for G-tolerance issues reside at the NADC. NADC resources were consulted on G-TIP design late in the systems design process, which prevented significant and important contributions to design. NADC is the only Navy facility with the experience and data base for G-TIP training, yet NADC has not been consulted officially on the “all important” training curriculum development. The G-TIP design specification has, as an option, the capability for aircrew SD training. Navy technical and database resources for SD reside at NAMRL. These resources remain untapped for formal technical input or participation in training system design. Involvement of these technical resources for the remaining phases of G-TIP development would markedly improve the opportunity to apply known technology to G-tolerance and SD training.

The optimal result of these information and integration efforts is an efficient matrix of informed workers and managers who can best maximize the unique assets and capabilities of their respective facilities to address technical issues as posed by the APS program.

In summary, the MED-02 organization should be challenged to ensure that their research and development efforts respond to the operational needs of the users.

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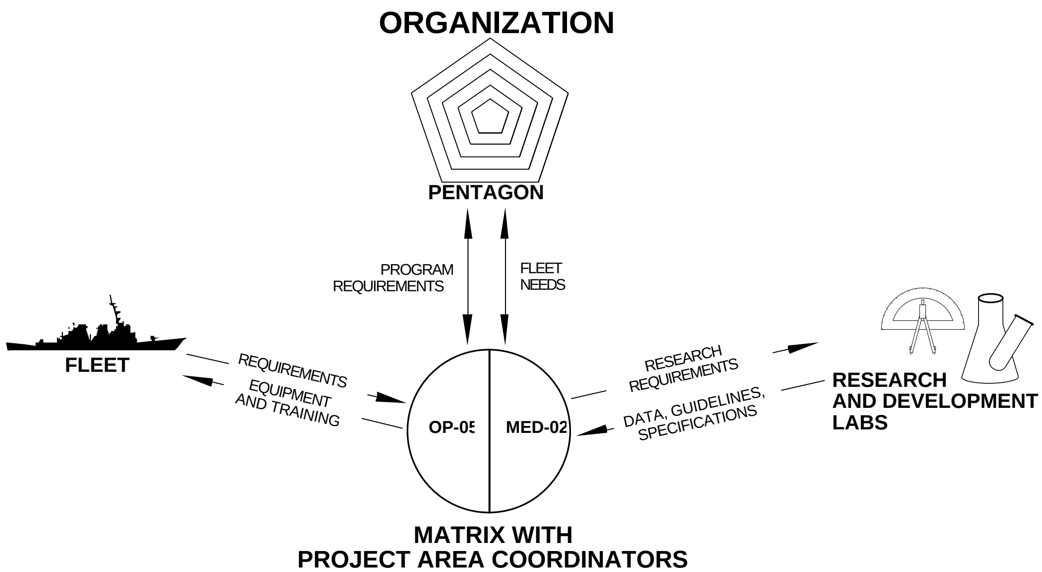

NRAC

SUMMARY & RECOMMENDATIONS

AVIATOR PHYSICAL STRESS

- **Aviator Physical Stress is increasing**
- **Navy must act now to minimize costly consequences**
- **Recommendations:**
  - **Organization accountability (OP-05/MED-02)**
  - **Annual progress report to ASN (RD&A)**
  - **Successfully retrieve operational APS data**
  - **Enhance training and conditioning**
  - **Focus research**
  - **Initiate equipment transition program**

Reduction of the consequences of Aviator Physical Stress will significantly improve naval aviation effectiveness

Summary

The degree and severity of physical stress upon the tactical aviator is increasing. Changes in the threat and tactical environment contribute directly to more demanding mission requirements, which translate to ever more agile aircraft. The combined effects result in both increased workload on the aviator as well as heightened exposure to physical stresses, the consequences of which include diminished mission effectiveness, pilot loss of confidence, pilot grounding, loss of equipment, and loss of life.

The Panel has analyzed available data and compiled a recommended set of interrelated actions which together contribute measurably toward reversing the incidence and severity of APS. In coming to these recommendations, the Panel considered technical solutions, focused research and data available from a myriad of sources, including USN, USAF, Royal Air Force (RAF) and other NATO air forces.

Every effort should be directed toward minimizing redundant research and data acquisition. Immediate and long-term actions are believed necessary in order to favorably influence the effects of APS. The Panel's proposed set of recommendations can lead to positive remedial effects in the shortest

possible timespan, ensuring cost-effective solutions to the problems associated with APS.

Recommendations

The Panel's recommendations address three specific aspects of APS. These are G-force induced neck injury, G-LOC, and SD. The recommendations are summarized as follows:

- Organization Accountability

  The Panel observed a noticeable absence of clear organizational lines of communication and responsibility/accountability. As a result, there are imperfections in data acquisition, information sharing, follow-up, and continuous improvement practices. Improvement in OPNAV and BUMED coordination and sponsorship in APS research, data collection, and training should be assured through a clearly defined functional organizational structure. This functional structure should be required to develop and implement an information network to facilitate technical data exchange. An annual status report should be submitted jointly from OPNAV and BUMED to the ASN (RD&A) providing the status of closure on the training, research, and equipment recommendations included in this report.

- Data Retrieved

  The Panel determined that obtaining and cataloguing comprehensive APS operational data are required. This data gathering is necessary to define the magnitude and frequency of G-LOC, neck injury, and SD occurrence. These data will be used to guide research (to include longitudinal analysis) and development, training modifications, and equipment requirement validation. It is recommended that OPNAV and BUMED establish mechanisms to gather and disseminate such data as a matter of routine reporting.

- Training

  Increased emphasis should be placed on G-awareness instruction, G-tolerance improvement, SD awareness, G-related injury potential, and physical conditioning. To be effective, such training must be conducted across the full spectrum of aviators, instructors, flight surgeons, aviation psychologists and physiologists. It is expected that such training emphasis will greatly strengthen the overall performance of aviators, while reducing risks of loss of equipment, loss of life, and diminished effectiveness of naval aviation.

- Research

  While some research has been directed toward understanding APS, there remain a number of specific areas of research in need of additional focused resource and priority support.

  G-LOC research should address the mechanisms and limitations of neurophysiologic and cardiovascular function, advanced high-G training, and protection devices.

  Further research into SD should be focused in areas including mechanisms of human motion control and spatial orientation, improved training scenarios and methods, improved orientation displays, and vestibular biomedical standards for flight status assessment, including improvements in clinical testing procedures.

  Finally, research keyed to reducing occurrences of neck injury is of equal importance. Results of research into the biodynamic effects of helmet system characteristics, neck size and strength, and head/neck position should be incorporated into equipment specification and training procedures.

- Equipment

  New and/or modified equipment can be employed to inhibit G-LOC, cervical injury, and SD. Equipment such as PPB and extended coverage G-suit systems should greatly enhance combat performance through both reduced fatigue and reduced potential for G-LOC.

  Current displays are not adequate to prevent SD mishaps. It is imperative that R&D be focused to ensure introduction of improved displays, controls, and decision aids systems to reduce pilot workload.

  The Panel is concerned over the growing number of helmet-attached accessories which contribute to helmet system weight. The Panel's recommended ceiling for helmet system weight (including mask) of 3.5 pounds should minimize the probability of increased incidence and severity of neck injury among aviators.

  Certain enhancements of the aircraft itself will be beneficial in reducing the risks of loss of equipment and loss of life. Among these are automatic ground proximity warning and autorecovery systems. Accident survivable in-flight data recording systems will contribute to our understanding of system failure when accidents do occur.

  Emphasis should be directed by OPNAV to ensure the timely transition of promising advanced engineering developments to fleet introduction.

APPENDIX A. GLOSSARY OF TERMS

APS	-	Aviator Physical Stress
ASDT	-	Advanced Spatial Disorientation Trainer
ASN (RD&A)	-	Assistant Secretary of the Navy (Research, Development and Acquisition)
BUMED	-	Bureau of Medicine and Surgery
CAF	-	Canadian Air Force
CNO	-	The Chief of Naval Operations
CNS	-	Central Nervous System
DOD	-	Department of Defense
FAA	-	Federal Aviation Administration
FRS	-	Fleet Replacement Squadron
G	-	Gravitational
G-LOC	-	G-Induced Loss of Consciousness
G-TIP	-	G-Tolerance Improvement Program
IAM	-	Institute of Aviation Medicine
MAWTS-1	-	Marine Air Warfare Training Squadron ONE, Marine Corp Air Station, Yuma, AZ
MSDD	-	Multi-Station Spatial Disorientation Demonstration
NADC	-	Naval Air Development Center, Warminster, PA
NAMI	-	Naval Aerospace Medical Institute, Naval Air Station, Pensacola, FL

NAMRL	-	Naval Aerospace Medical Research Laboratory
NASA	-	National Aeronautics and Space Administration
NATO	-	North Atlantic Treaty Organization
NAVAIR	-	Naval Air Systems Command
NBC	-	Nuclear, Biological and Chemical
NBDL	-	Naval Biodynamics Laboratory, New Orleans, LA
NMRDC	-	Naval Medical Research and Development Command, National Naval Medical Center, Bethesda, MD
NRAC	-	Naval Research Advisory Committee
NSC	-	Naval Safety Center
OAG	-	Operator Advisory Group
OPNAV	-	Staff of the Chief of Naval Operations
PPB	-	Positive Pressure Breathing
R&D	-	Research and Development
RAF	-	Royal Air Force
RNLAF	-	Royal Netherlands Air Force
SD	-	Spatial Disorientation
TACAIR	-	Tactical Aviation
TOR	-	Tentative Operational Requirement
USA	-	United States Army
USAF	-	United States Air Force
USAFSAM	-	United States Air Force School of Aerospace Medicine

USMC	-	United States Marine Corps
USN	-	United States Navy
VF-126	-	Fighter Squadron ONE TWO SIX (Adversary) - Naval Air Station, Miramar, CA
VX-4	-	Air Test and Evaluation Squadron FOUR - Naval Air Station, Point Mugu, CA
VX-5	-	Air Test and Evaluation Squadron FIVE - Naval Weapons Center, China Lake, CA